Libera's Split-shortwave Measurement: Applications in Climate Studies

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CERES-Libera STM, May 2021

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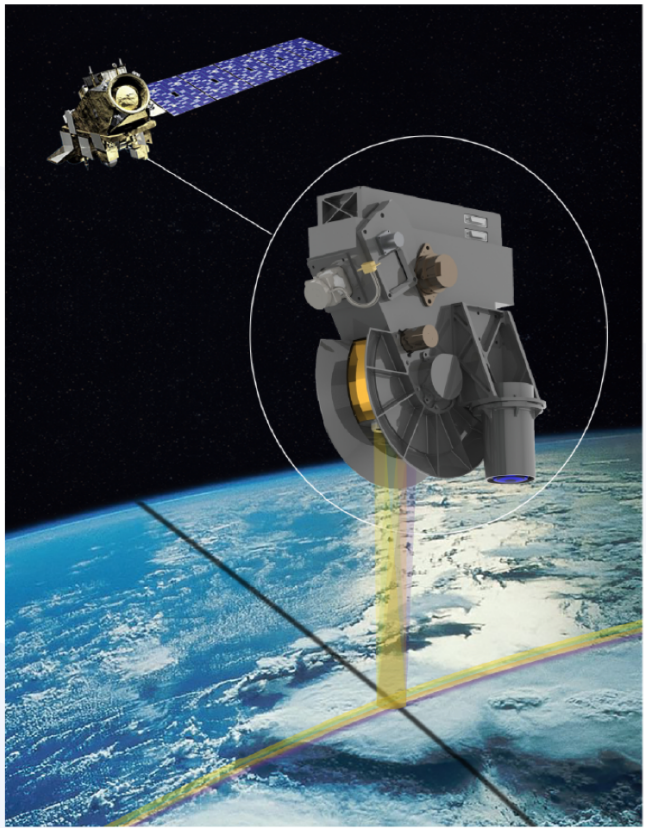
Libera, NASA's first *Earth Venture* ***Continuity*** Mission

Overarching Science Goals



OG1: Provide seamless continuity of the Clouds and the Earth's Radiant Energy System (CERES) ERB Climate data record (CDR).

- Measurement of TOT, SW and LW with same characteristics as CERES to prevent gap in ERB Climate data record.

OG2: Advance the development of a self-contained, innovative & affordable observing system.

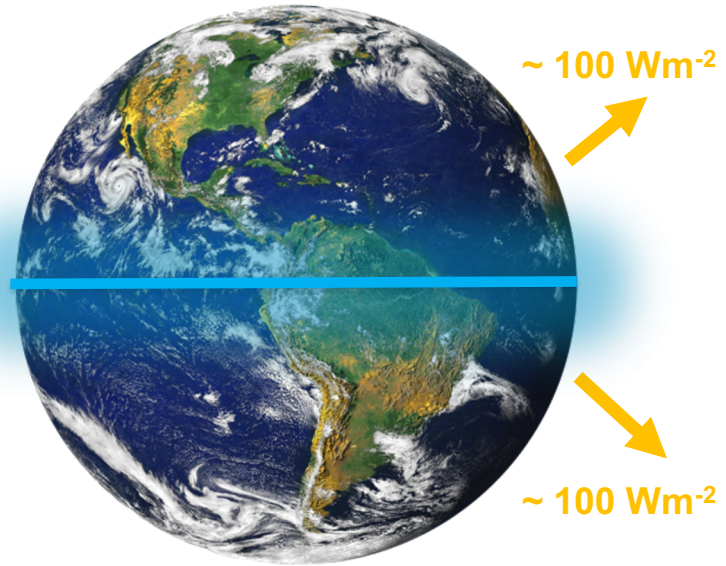
- Wide field-of-view camera for Scene ID and split-SW ADM development.

OG3: Provide new and enhanced capabilities that support extending ERB science goals.

- **Additional split-SW channel to quantify shortwave near-IR and visible flux.**

Libera's shortwave sub-band measurement

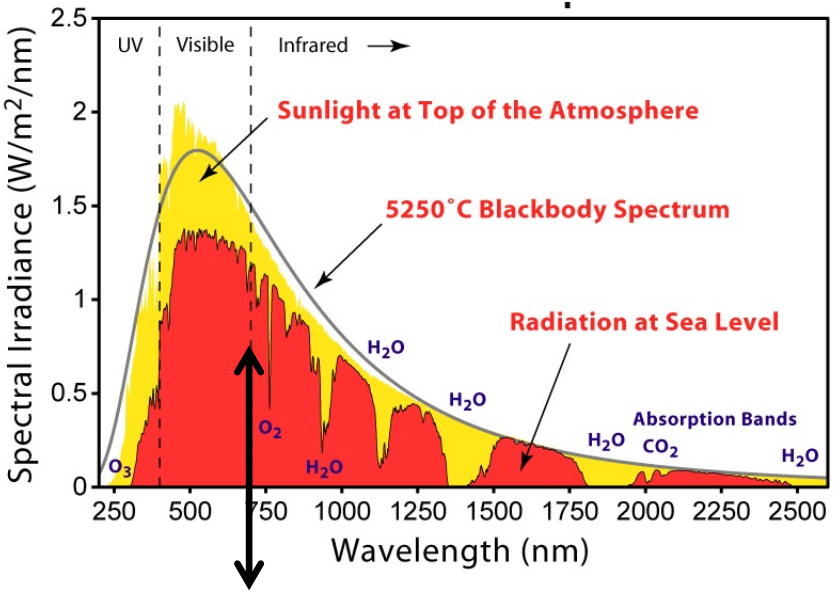
- Libera's fourth channel measures VIS at the same accuracy as the total SW radiance (0.17%)
- Retrieval of VIS, NIR, SW fluxes at TOA and surface:
  - VIS radiances are measured at 0.3-0.7 µm
  - SW radiances are measured at 0.3-5 µm
  - Conversion to VIS flux using WFOV camera radiances at 555nm **(J. Gristey, S. Schmidt)**
  - NIR = SW - VIS
- **Goals:**
  - NIR & VIS signatures of processes that control the **absorption of solar radiation** & SW climate feedbacks.
  - Better understand the **hemispheric symmetry of planetary albedo.**
  - Quasi-spectral model evaluation to reveal process-related biases



SW reflection may be symmetrical, but spectral "fingerprint" may not!

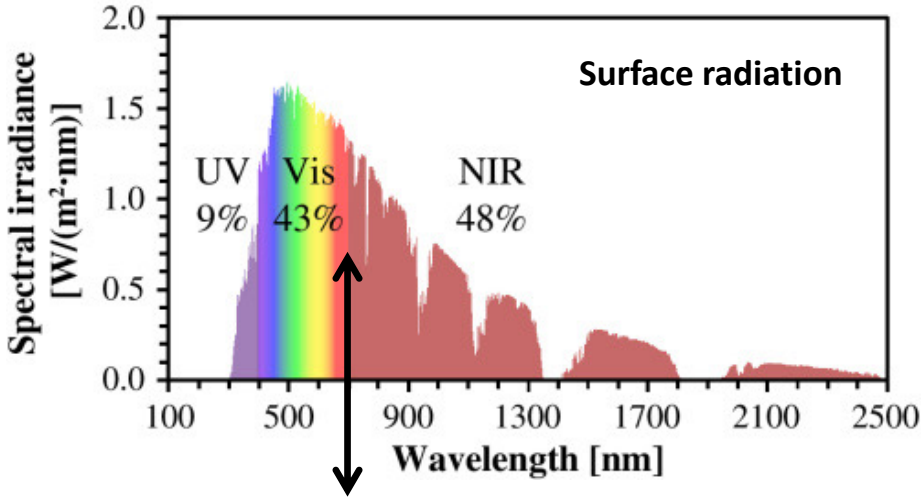
Models do not represent this symmetry well resulting in errors in circulation & precipitation patterns.

Spectral nature of shortwave radiation



Libera "split" at 700nm

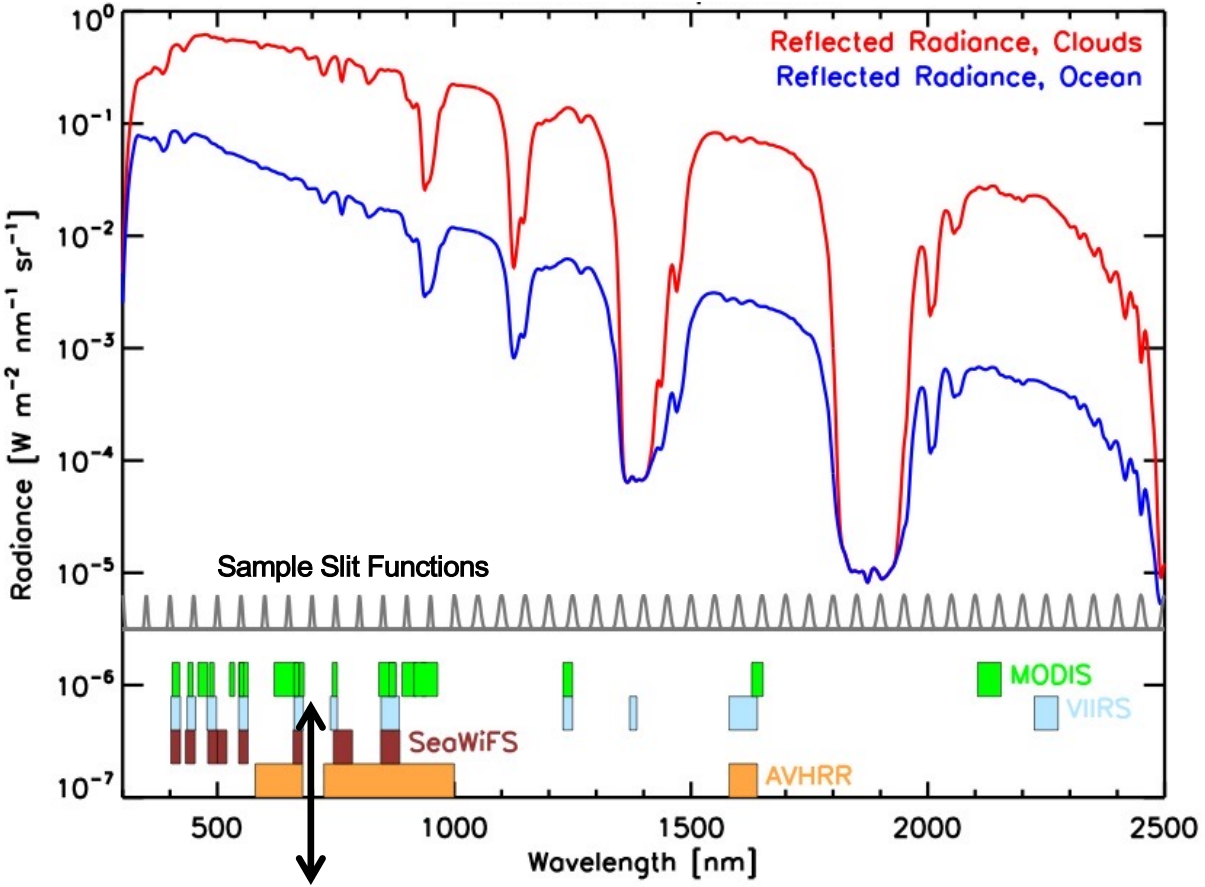
Energetically,
incoming VIS = incoming NIR.



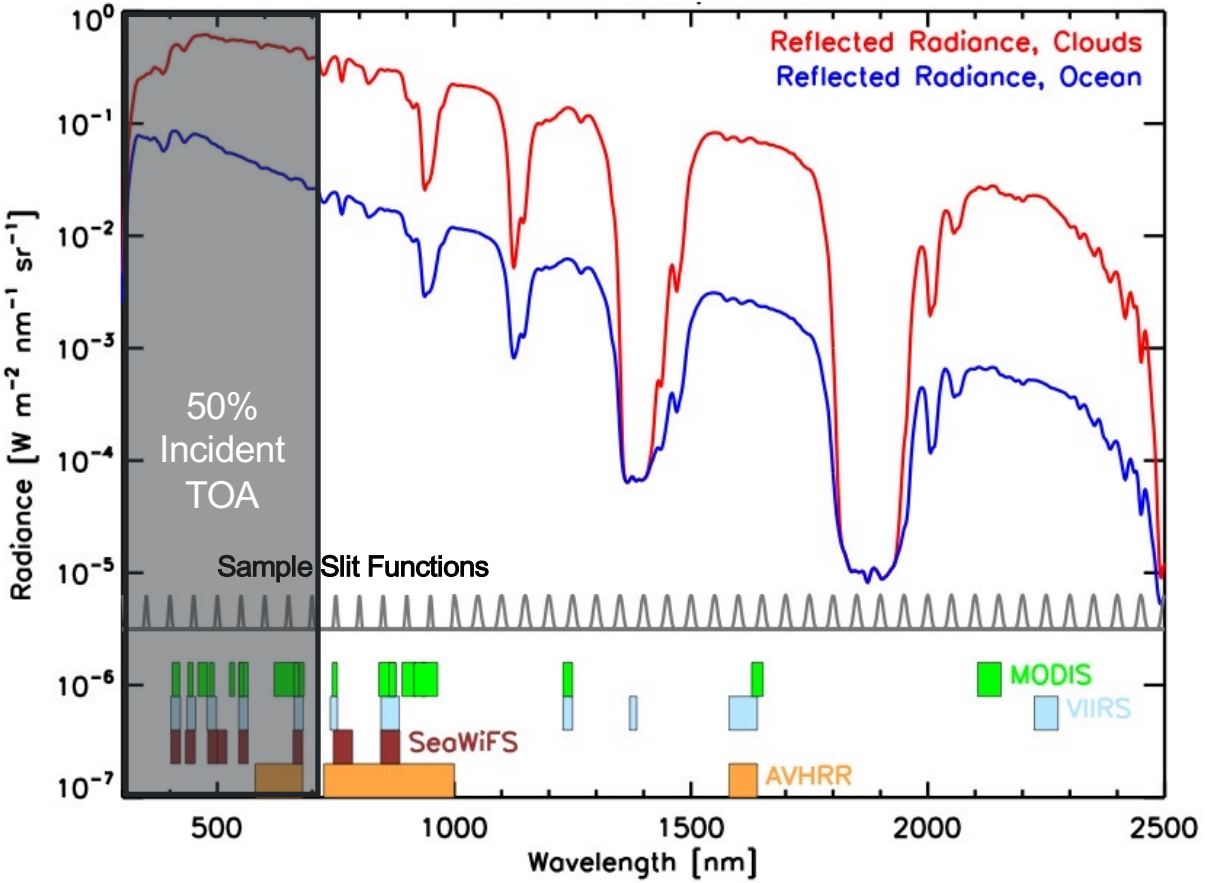
Energetically,

surface incoming VIS ≈ incoming NIR.

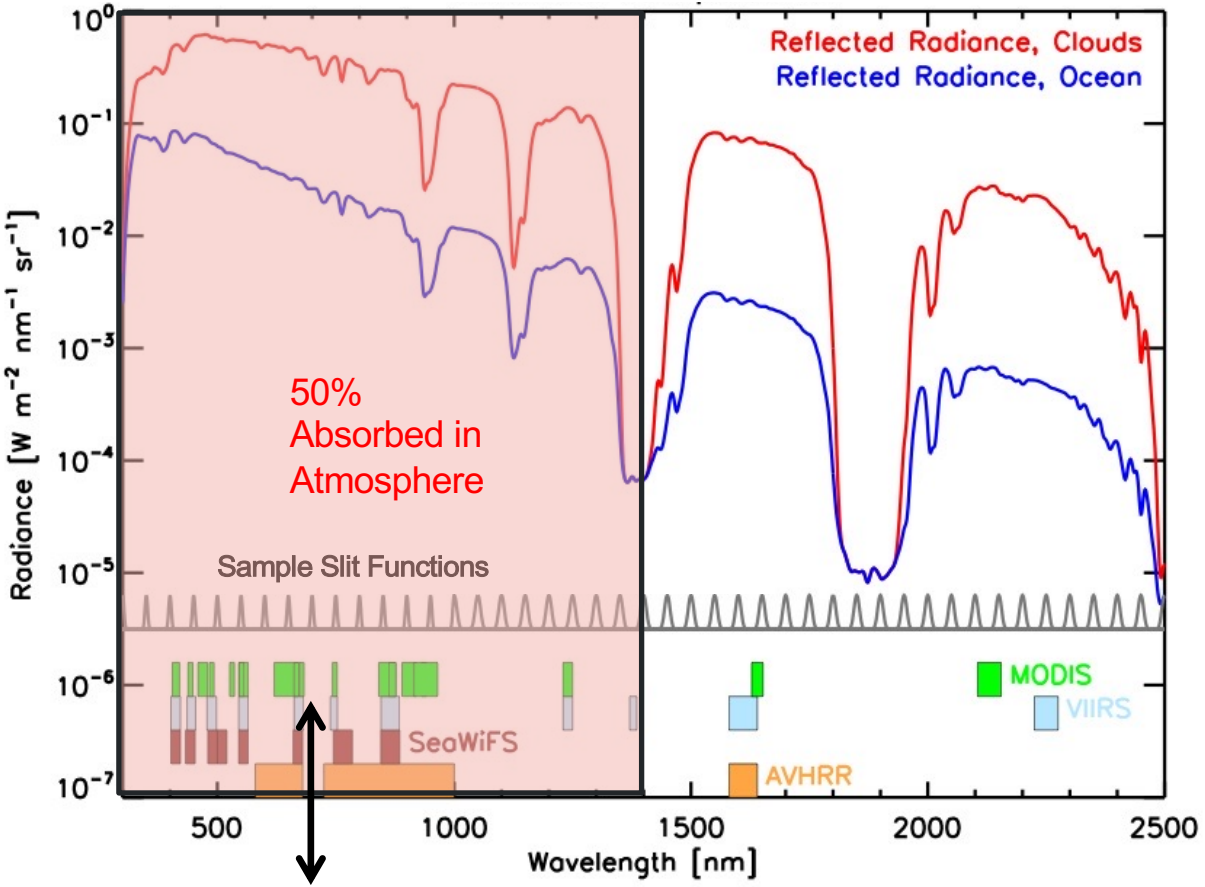
Cumulative Incident and Absorbed Solar Radiation



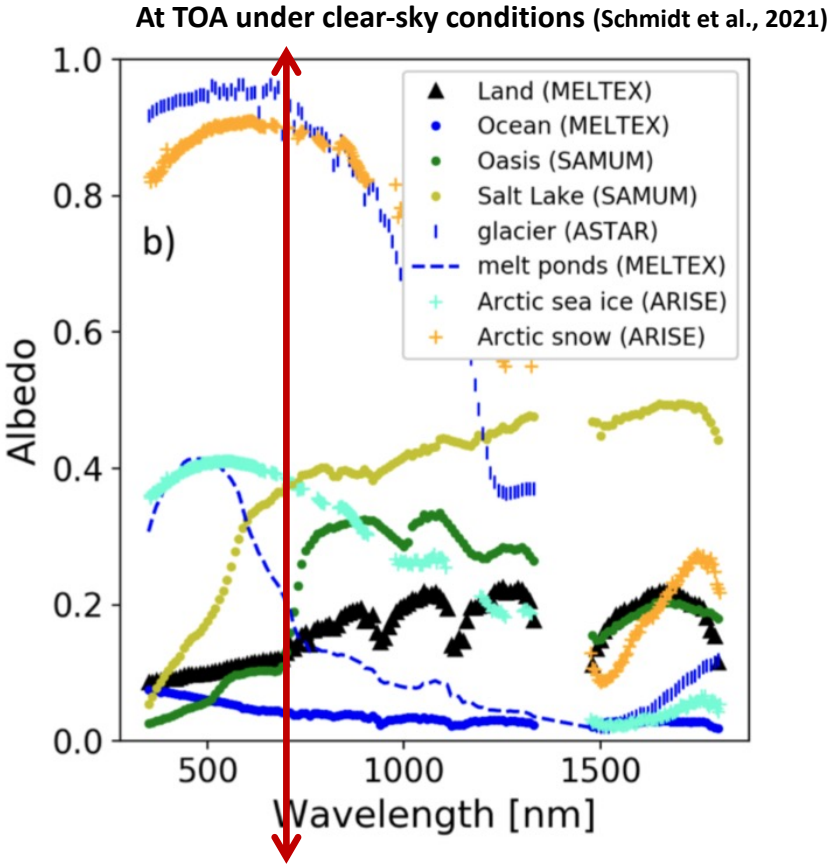
Cumulative Incident and Absorbed Solar Radiation



Cumulative Incident and Absorbed Solar Radiation



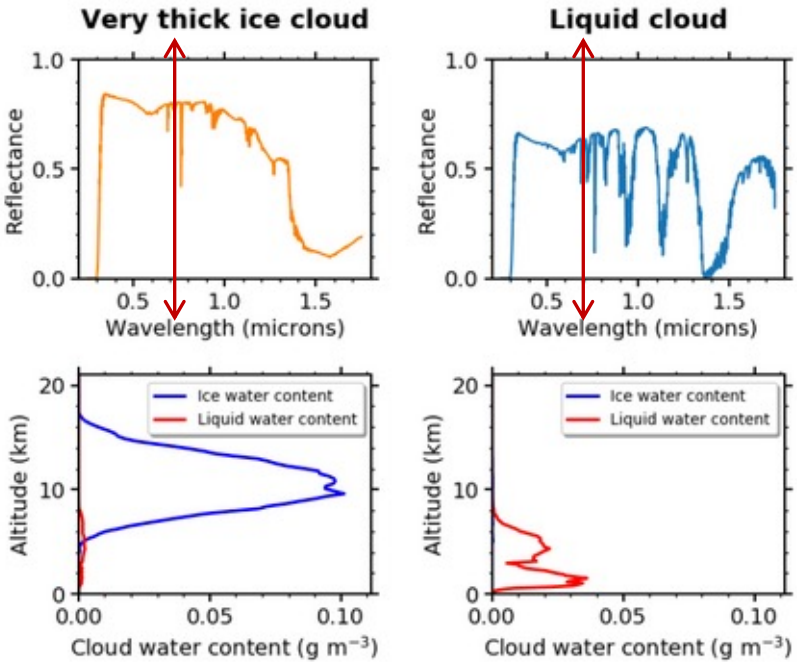
Shortwave spectral information - surface



- Aircraft surface albedo measurements for validation
- Snow and ice albedo decreases in NIR (snow is darker) – cloud retrievals
- Vegetation step: sudden increase in NIR albedo over vegetated land (vegetation is bright) – NDVI retrievals

Shortwave spectral information - clouds

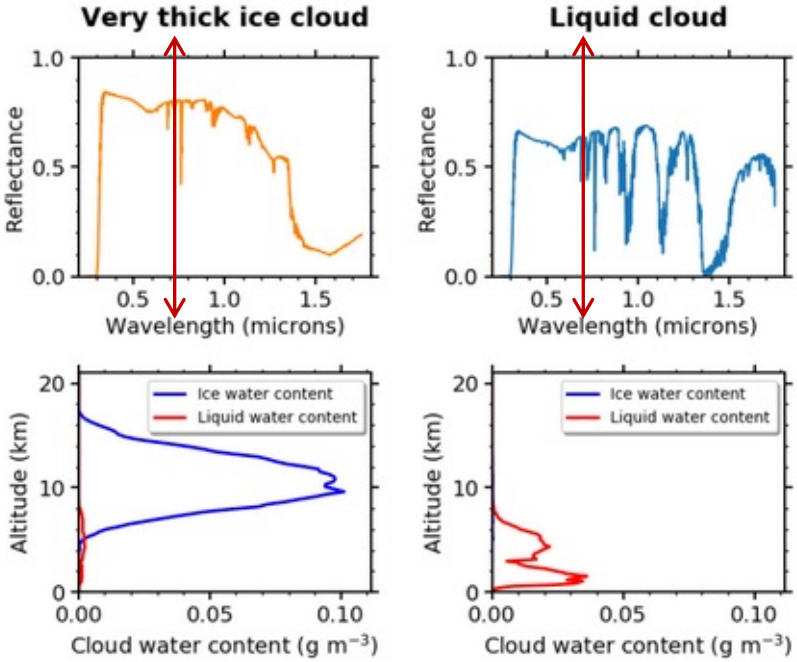
SCIAMACHY Spectra over West Africa (Gristey et al., 2019)

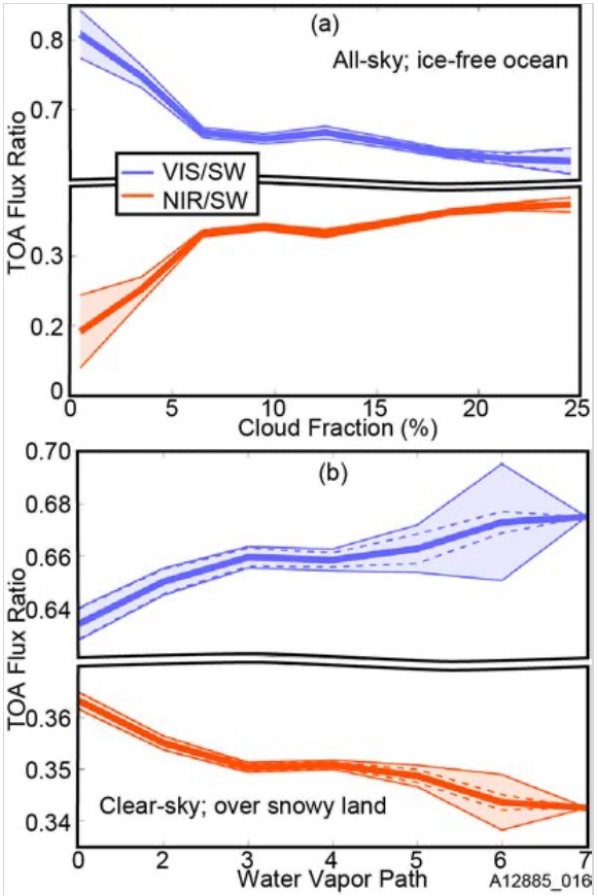


- High ice cloud is bright both in VIS and NIR, but ice absorbs near 1.5 µm
- Low liquid cloud less bright, additional NIR absorption by water vapor
- What is cumulative effect on NIR and VIS? Previous OSSE analysis suggests: over ocean, NIR reflection increases more relative to VIS.

Shortwave spectral information - clouds

SCIAMACHY Spectra over West Africa (Gristey et al., 2019)

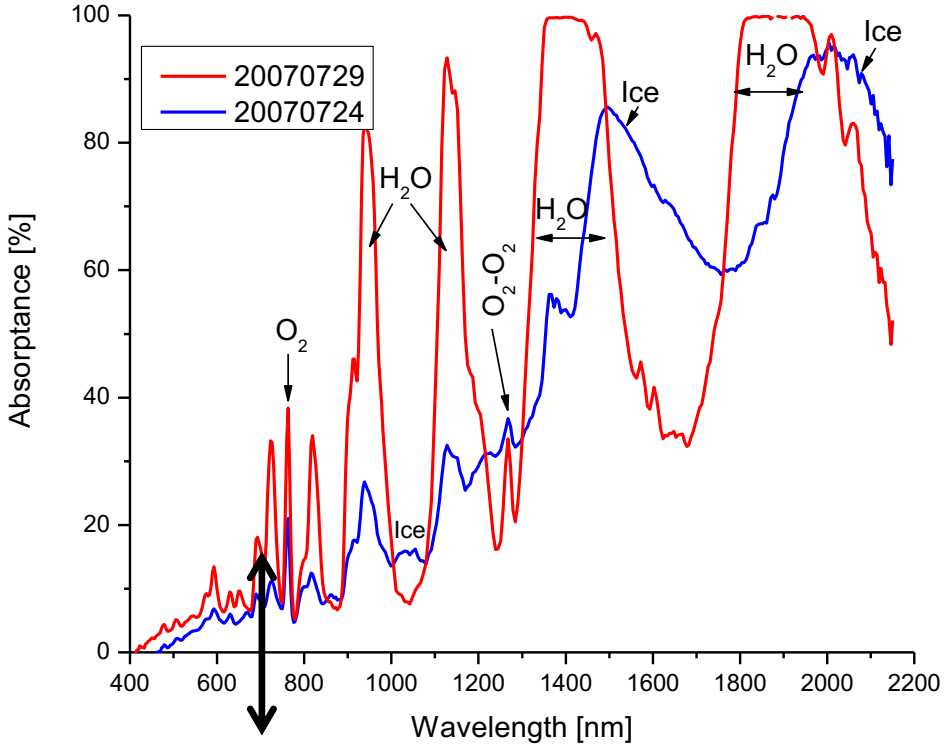


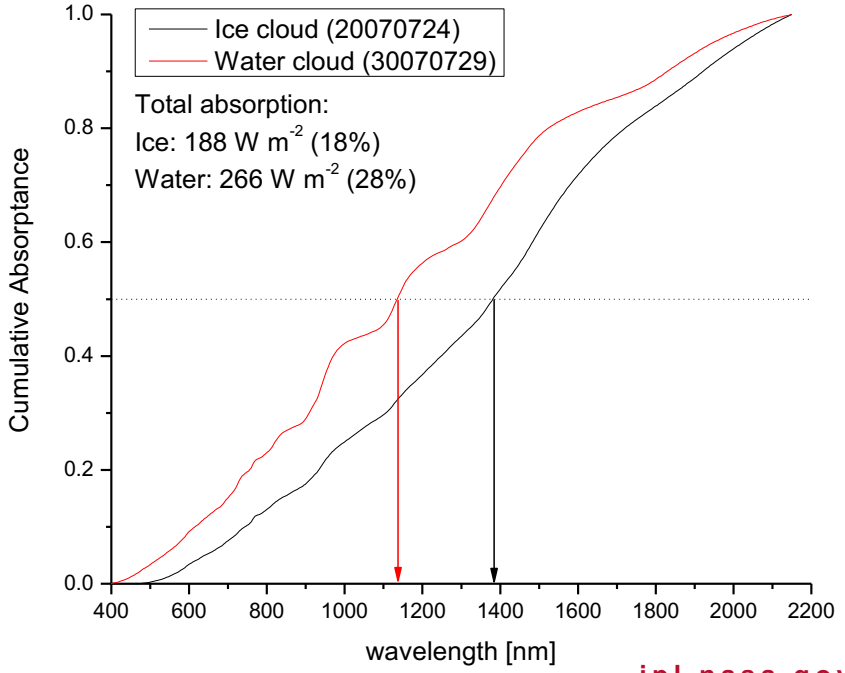


Next: Spectral radiative kernels by D. Feldman to quantify sensitivities.

Shortwave spectral information - clouds

Water Cloud vs. Ice Cloud Column Absorption Derived from Measurements: tropical above-below cloud solar irradiance spectra **(Schmidt and Pilewskie, 2012)**





What's Libera going to help with?

NOT a spectral measurement

- But Libera split represents a first tiny step toward spectral or quasi-spectral radiation budget measurements.

- Aspects of the Earth radiation budget variability form quasi-spectral perspective.

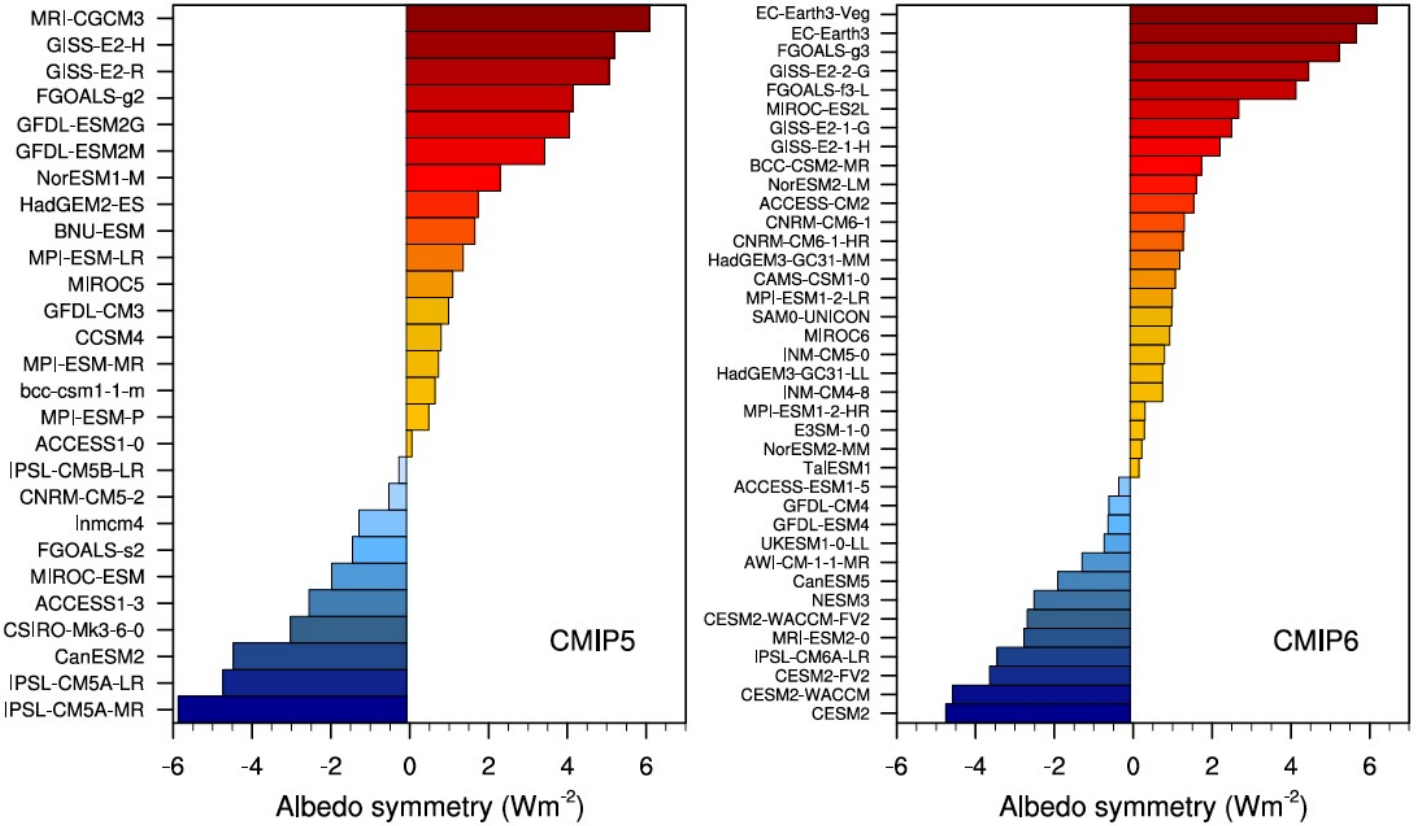
- More probing model evaluation

Climate studies with an ESM

Why hemispheric albedo symmetry?

NH-SH TOA SW flux in CMIP5 and CMIP6

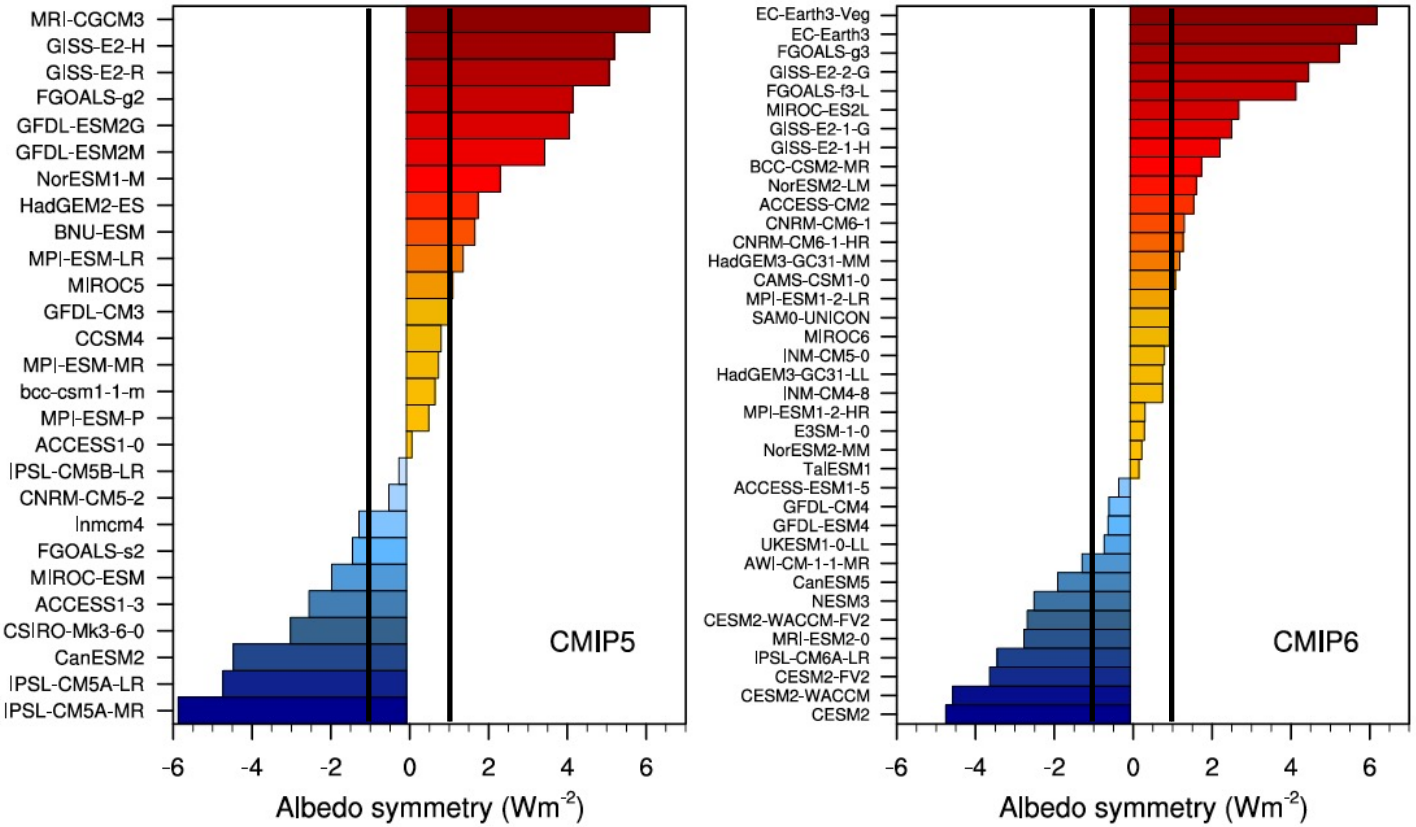
Many climate models do not reproduce albedo symmetry (?)



Model analysis:
Maria Rugenstein

NH-SH TOA SW flux in CMIP5 and CMIP6

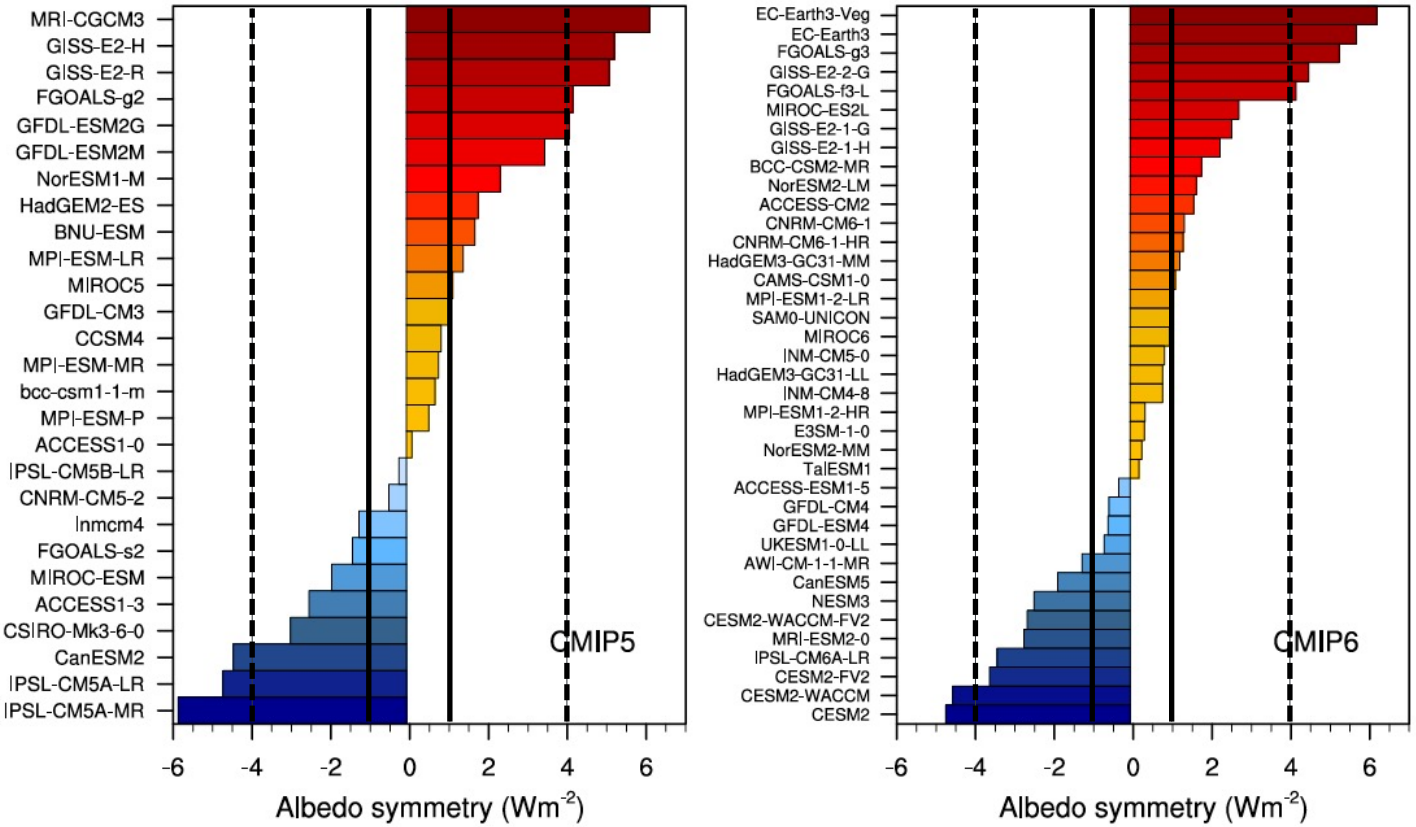
30% of models are symmetric within ± 1 Wm^{-2}



NH-SH TOA SW flux in CMIP5 and CMIP6

70 (80)% of models are symmetric within ± 4 Wm^{-2}.

(An asymmetry of 4 Wm^{-2} in the hemispheric energy budget would imply 3 times more heat transport across equator!)



UKESM1 SW, NIR, and VIS fluxes

- UK Earth system modeling project
- Successor to HadGEM2-ES
- “The complexity of coupling between the ocean, land, and atmosphere physical climate and biogeochemical cycles in UKESM1 is unprecedented for an Earth system model.” (Sellar et al., 2019)
- Limits of spectral intervals (wavelengths in m.)

Band	Lower limit	Upper limit
1	2.000000000E-07	3.200000000E-07
2	3.200000000E-07	5.050000000E-07
3	5.050000000E-07	6.900000000E-07
4	6.900000000E-07	1.190000000E-06
5	1.190000000E-06	2.380000000E-06
6	2.380000000E-06	1.000000000E-05

- Integrate bands 2-3 for visible, and bands 4-5 for near-IR

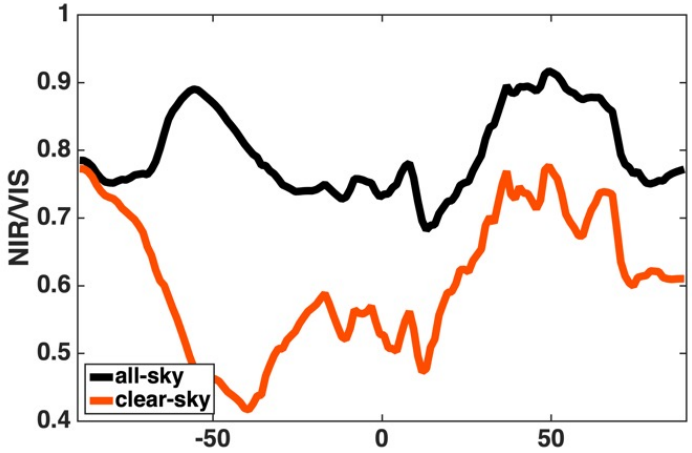
Model simulation:
Alejandro Bodas-Salcedo

UKESM1 is “symmetric” (20y pi control)

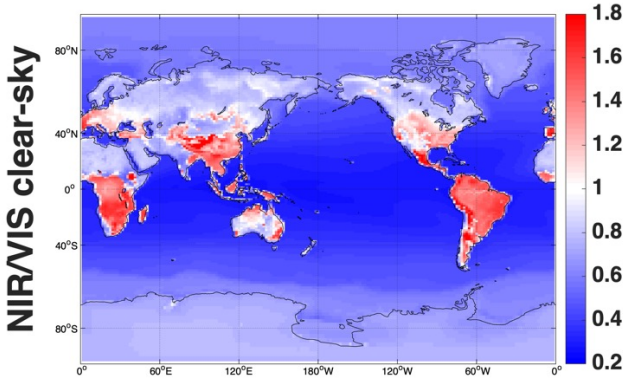
All-sky	Glo	NH	SH
TOT SW	99.3	**99.1**	**99.6**
NIR	44.0	44.2	43.7
VIS	55.0	55.8	55.4
NIR/VIS	0.79	0.80	0.78
Clear-sky	**Glo**	**NH**	**SH**
TOT SW	54.4	57.4	51.4
NIR	20.2	22.3	18.2
VIS	34.2	35.1	33.2
NIR/VIS	0.59	0.63	0.55

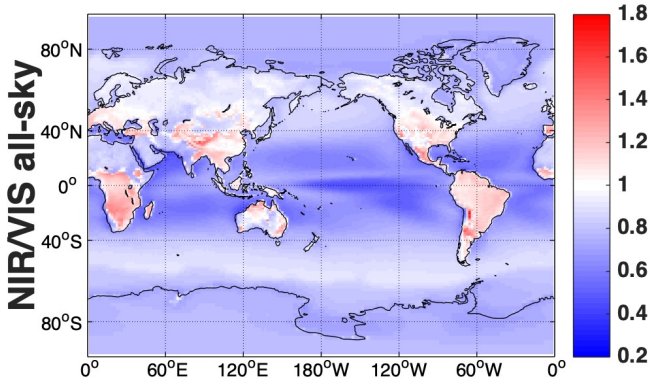
- Model is symmetric in total SW, NIR and VIS under all-sky conditions
- Cloud radiative effects (CRE) increase and hemispherically balance NIR/VIS!
  - Model shows no hemispheric spectral difference
  - Clouds - over SH ocean in particular - enhance NIR/VIS
- Clear-sky asymmetry (total SW: 6 Wm^{-2}) is mostly a NIR asymmetry (4 Wm^{-2})

UKESM1 NIR/VIS per latitude

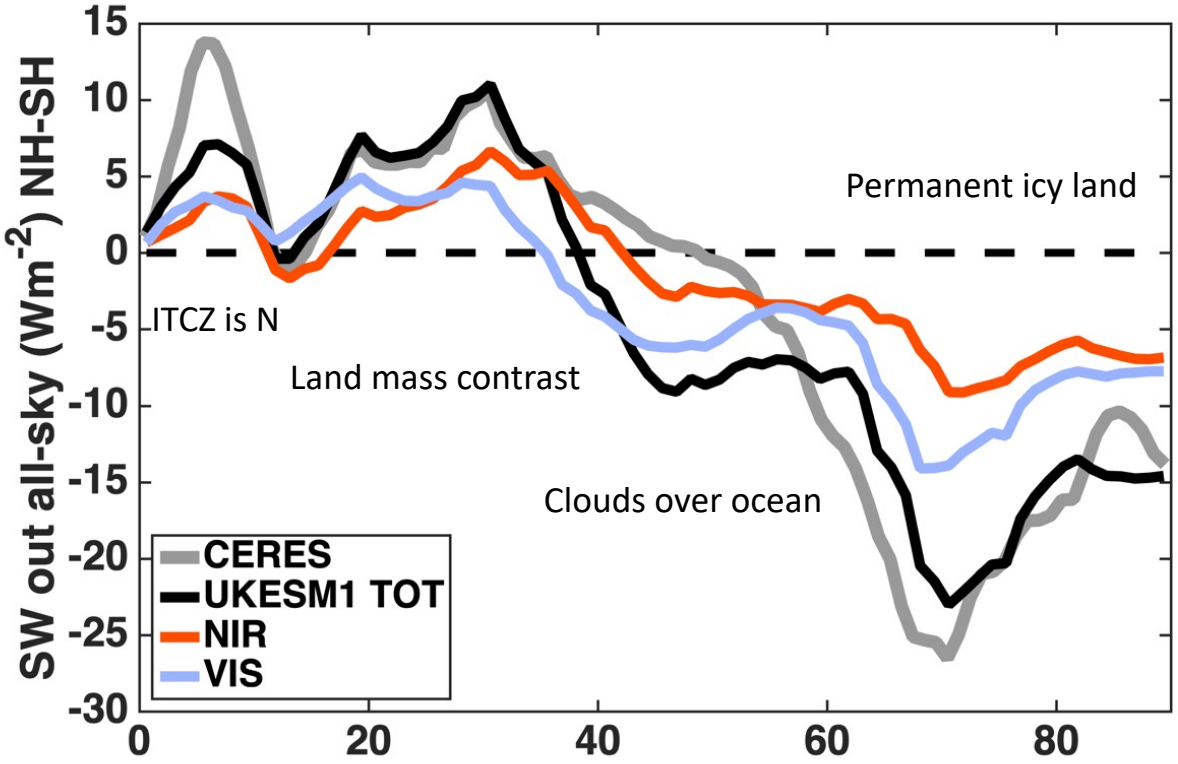


- Clear-sky asymmetry is a hemispheric “land-sea contrast”, where NIR/VIS higher over land
- Highest NIR/VIS in Southern Africa and South America! (but outweighed by vast ocean low NIR/VIS)
- CRE increase NIR/VIS especially over SH ocean
- CRE diffuse spatial gradients in NIR/VIS



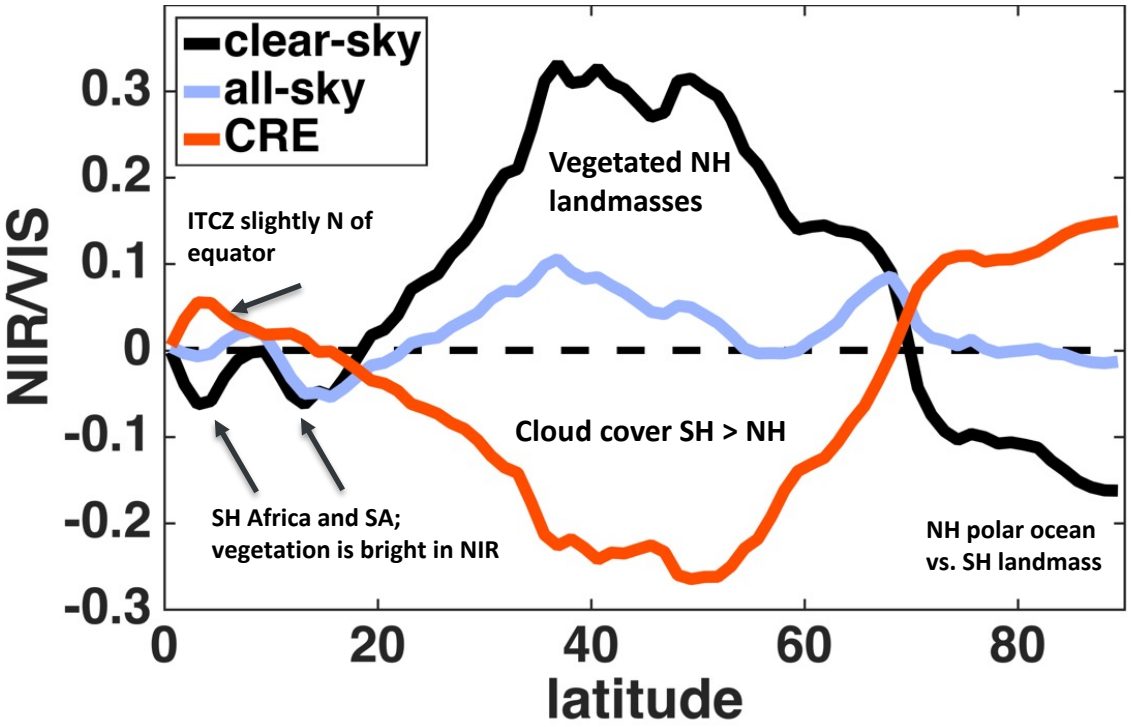


NH-SH differences per latitude



- NH is mostly brighter over 0-40 degree, but darker poleward
- Model agrees OK with CERES
- NIR & VIS zonal variability looks similar to total SW…

NH-SH differences NIR/VIS ratio per latitude



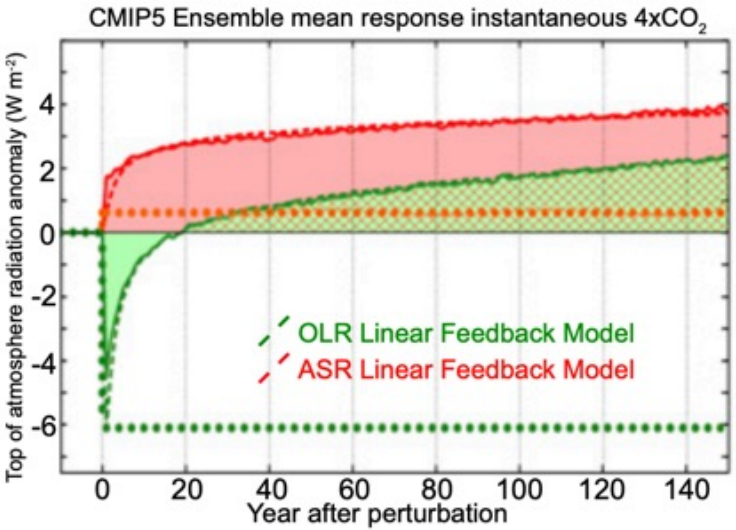
- Positive values: NIR/VIS ratio is larger on NH than on SH; especially true under clear-sky between 20-70 deg. (note: locally, SH Africa and SA have largest NIR/VIS)
- CRE balance the hemispheric NIR/VIS ratio zonally & mirror the Clear-sky effects.
- But NIR/VIS ratio remains slightly larger on NH under all-sky conditions.

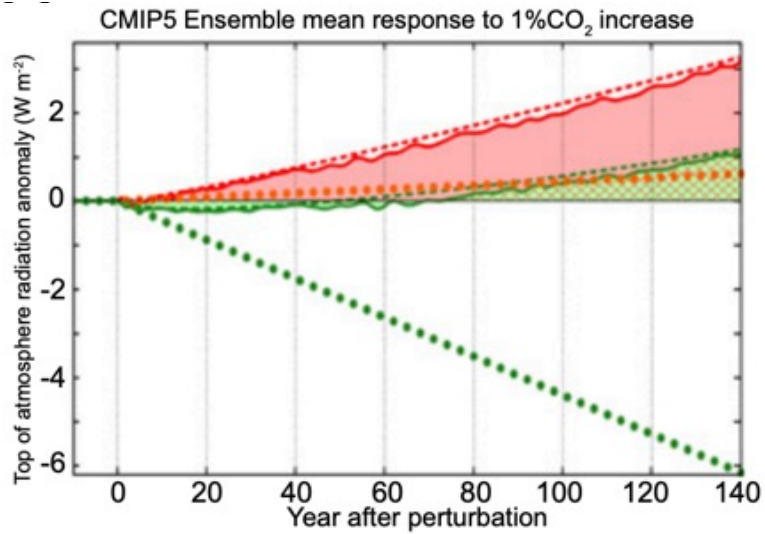
Climate studies with an ESM

Why shortwave absorption?

Time evolution of NIR & VIS

Climate model simulations under different future scenarios suggest global warming on decadal to centennial time scales is kicked-off by OLR reduction but largely sustained by enhanced shortwave absorption (positive climate feedbacks).



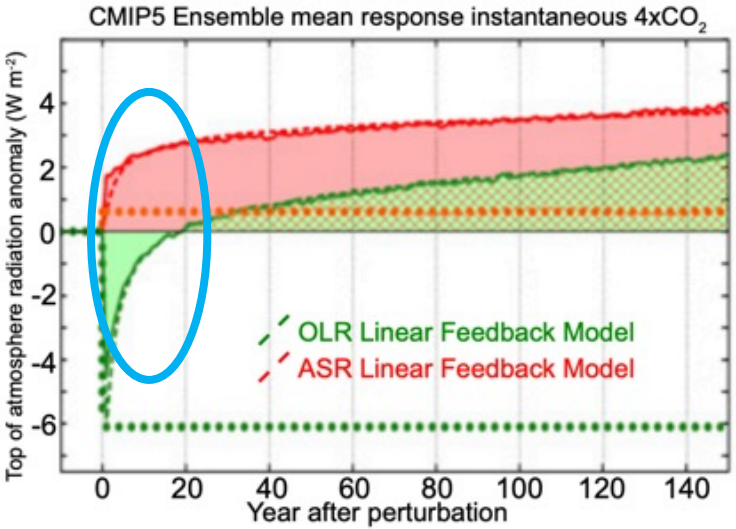


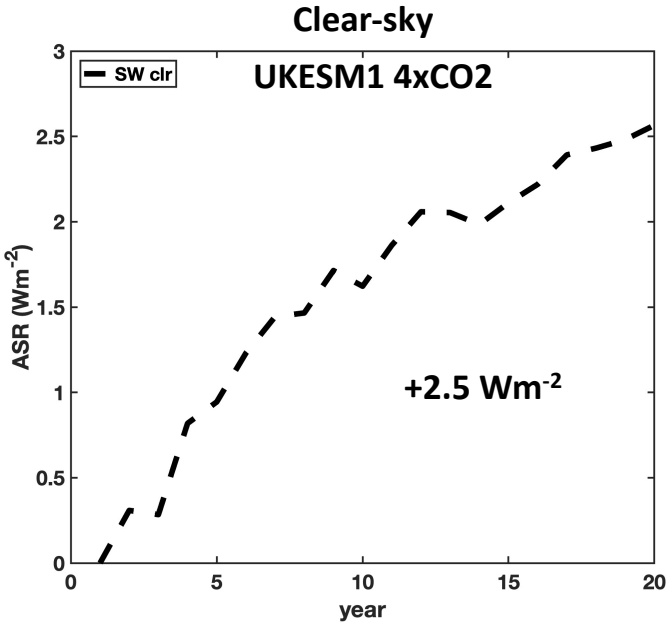
Clear-sky only

Donohoe et al., 2014

Time evolution of NIR & VIS

Climate model simulations under different future scenarios suggest global warming on decadal to centennial time scales is largely sustained by shortwave absorption (positive climate feedbacks).

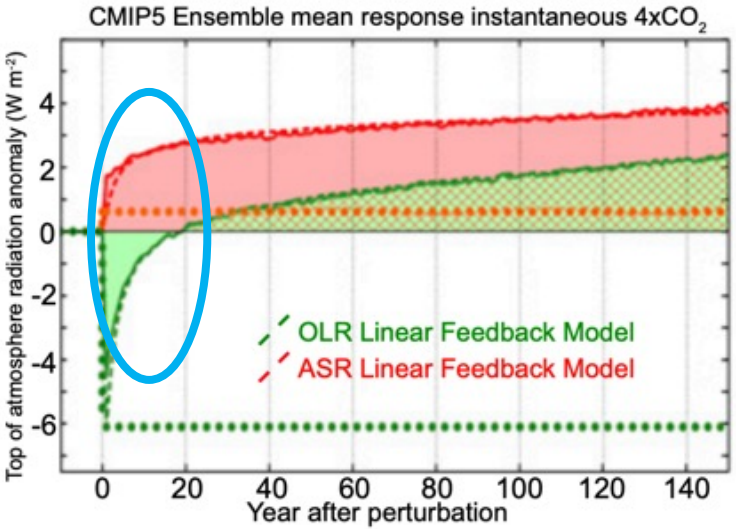


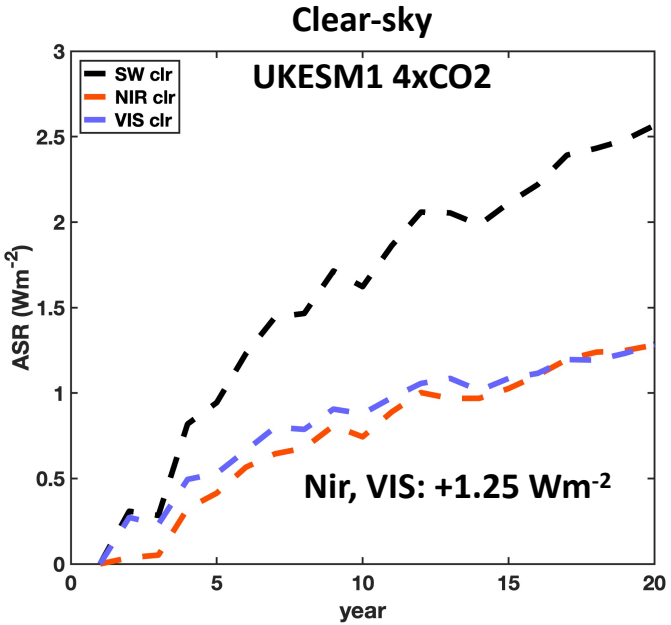


Both the multi-model mean (left) and UKESM1 (right) analyses show a similar ~2.5 Wm^{-2} increase in clear-sky absorption of solar radiation (ASR) after about 20 years in the 4xCO_2 scenario.

Time evolution of NIR & VIS

Climate model simulations under different future scenarios suggest global warming on decadal to centennial time scales is largely sustained by shortwave absorption (positive climate feedbacks).

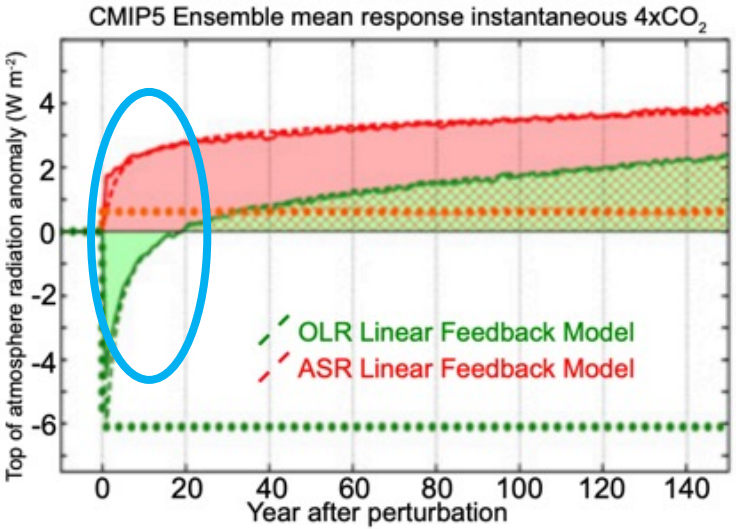


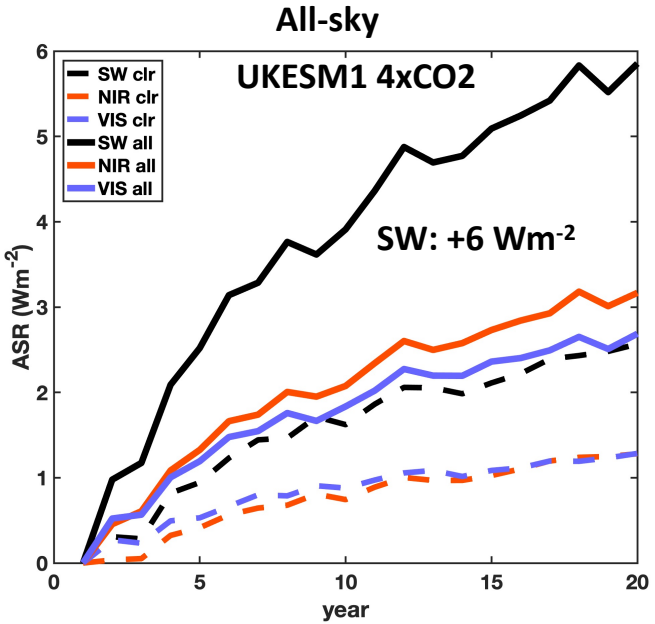


Increases in clear-sky NIR and VIS are equally as important at **+1.25 Wm^{-2}**

Time evolution of NIR & VIS

Climate model simulations under different future scenarios suggest global warming on decadal to centennial time scales is largely sustained by shortwave absorption (positive climate feedbacks).

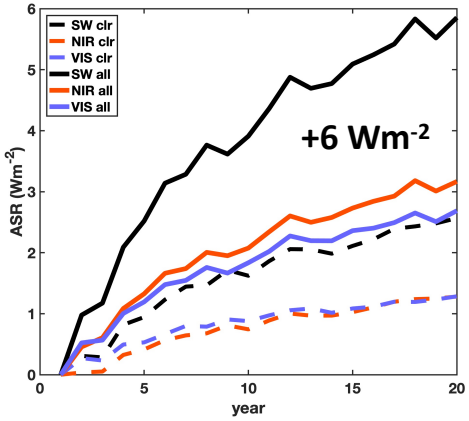




ASR more than doubled to 6 Wm^{-2} under all-sky conditions:
Positive cloud feedback; NIR effect slightly larger

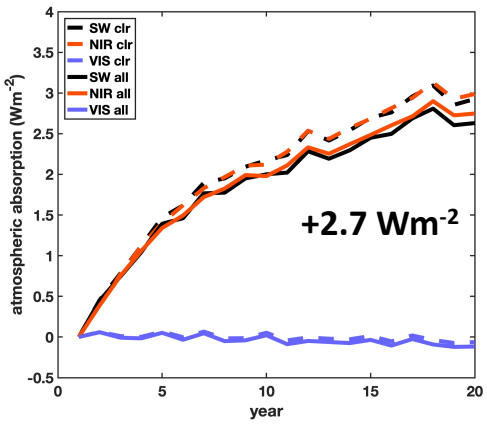
20-year ASR at surface vs. in atmosphere

ASR at TOA



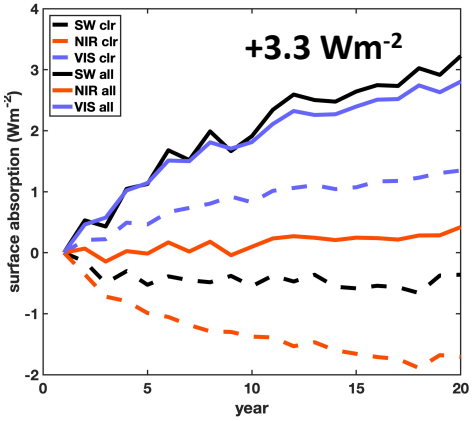
- Clouds double ASR: VIS surface effect (~40% SA + ~60% cloud+ feedback)
- Clear-sky: atmospheric ASR in NIR (water vapor feedback)

Atmospheric absorption

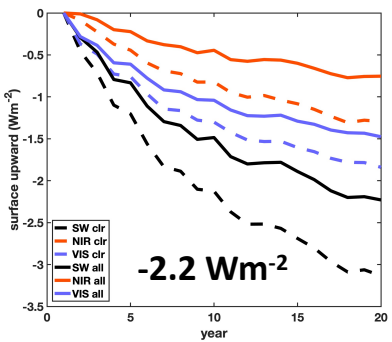


- SW atm. ASR = NIR atm. ASR
- Clear-sky: total ASR = atm. ASR in NIR
- All-sky: atm ASR is 45% of total ASR increase

Surface absorption



Surface upward



- Surface upward flux decline in NIR and **VIS:** albedo is darkening
- Surface ASR mostly in VIS (albedo ~70% + increase in downward ~30% radiation); NIR surface clr decrease ~ NIR atm clr increase
- NIR all-sky: positive CRE cancel negative water vapor

ASR increase = 45% atmosphere (NIR minus tiny bit VIS) + 55% surface feedbacks (VIS plus tiny bit NIR)

Conclusions

- Libera carries a fourth “shortwave split channel”
- Split at 700 nm to distinguish between solar radiation that is absorbed by the clear atmosphere (NIR) and in which vegetation is bright vs. radiation for which the clear atmosphere is mostly transparent (VIS) and snow is bright
- Albedo symmetry is an accumulation of processes that differ per hemisphere and affect the NIR/VIS ratio; UKESM1: Clouds balance clear-sky asymmetries in total SW AND in NIR/VIS especially over the Southern Ocean
- The increase in solar absorption with “climate change” in UKESM1 occurs both in the VIS (surface albedo + clouds) and NIR (water vapor), while NIR slightly dominates (adds to surface absorption). More models to assess NIR/VIS fingerprints!
- Libera will serve to quantify relevant sensitivities & to evaluate climate models